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OPTICAL COMMUNICATION APPARATUS AND METHOD

The invention relates generally to communication systems, and in particular, to optical communication systems including specifically switches for directing optical data signals along paths in an optical communications network.

A typical large scale network has a plurality of hubs or nodes through which data passes. The data signals are most likely to be data packets including a data portion and surrounding header and trailer information. The hubs typically read header information from the incoming packetized signals and, like a traffic cop, direct the signals to the correct outbound path. The packets are assembled according to a protocol specification, or standard. The header information can indicate in accordance with existing protocol standards, the destination address, the source address, the length of the data message, etc.

Networking technologists are constantly searching for ways of improving the throughput and speed of the network. The greater the throughput and speed, the higher the capacity of the network. Typically, the network thus becomes more efficient and productive. In order to provide very large “pipes” or message carrying lines, optical fiber has become a medium of choice. Optical fiber has broadband characteristics, and can enable a very high bandwidth, and hence large “pipe”.

Optical communications networks, however, that is, networks using optical fiber as the communications path medium, still have a major constriction: the switching of the optical input signal from an input path to a selected output path at a router or bridge. Theorists have discussed using an all optical switching router or bridge, but have not known how to achieve that goal. Thus, despite the bandwidth provided by the optical

fiber transmission line, the bandwidth cannot be fully utilized because, the signals on the fiber, in accordance with prior art practice, are converted at the router from an optical signal (the form in which they pass through the fiber) to an electrical signal for processing at the switch.

The switch processes those electrical signals by determining from those signals the destination of the incoming data (typically packets) and the protocol and format of the data, and sets the appropriate switch controls to direct the data to the correct output port. Each of these processes requires a processing time in the router and accordingly, the optical signal, if it is "stored" in the router for retransmission on to a next destination node or end user, is typically passed through a substantial length of optical fiber acting as a delay loop or buffer. The length may be, for example, a mile or more, and the fiber is housed within the router. Thus, the data is presented to the correct output port only after that output port has been determined "electrically". (Alternatively the electrical signal can later be converted back to an optical signal as the signal, repackaged if necessary, continues along its path toward the destination.) As the data signal is converted between optical and electrical components, substantial time is lost and the full bandwidth capacity of the optical fiber is reduced as the data is buffered, and read. The need to connect to electrical signal processing reduces throughput, inserts additional delays and makes the overall transmission process less efficient.

Summary of the Invention

The invention relates to an optical signal processing method and apparatus and features an optical signal router having a plurality of optical switches arranged in a connection structure, each switch having at least one optical input port, at least a first

and a second optical output port, and an optical control port for controlling the optical connection of a switch input port to one of the switch's output ports. An optical control generator has a plurality of electrically controlled optical energy sources, each source being optically connected to at least one of said optical control ports, each source having an electrical signal input control port and an optical energy output port in response thereto. A processor translation system for flexibly generating and controlling electrical signals input to a plurality of the electrical control ports of the optical source, configures the connection structure for managing the optical route of an optical data input signal through the processing system to a processing system selected output.

The optical switches thus are connected in a structure for enabling a network input optical data signal to be directed to the correct output port. A software implemented system, a hardware implemented system, or a combination hardware/software implemented system implements controlling signals for flexibly controlling the electrical input to the input control ports of the optical sources.

In a particular embodiment of the invention, the optical switch structure is interconnected, in a manner analogous of its electrical counterpart, the programmable array logic, to process the incoming optical data, optically. In this aspect, the system and method determine, for example, the beginning of an optical packet, and optically process the optical packet to generate, for example, destination and length information so that the optical packet can be properly directed to an output port without delay. This system and method, accordingly, also determine the end of an input optical packet and the beginning of the next packet so that it too can then be processed in accordance with information contained within the optical packet. The signals which control the optical

processing are also determined optically without ever converting the input optical signal to electrical pulses. The configuration of the optical network, consisting of interconnected optical switches, is determined using the protocol specification corresponding to the incoming signal data, converted to electrical signals for controlling optical sources which in turn control and configure the optical devices. The optical device configuration can be flexibly altered, without human intervention, as new protocols become available and are converted, automatically, by the system and method of the invention.

In a particular embodiment of the invention, the software implemented system features a processor for implementing instructions for accepting a protocol specification that includes a plurality of specifications of element input/output relationships, wherein the specifications of at least some of the elements are in terms of sequences of other of the elements. The system further features instructions for associating portions of the specification with control levels of the electrical signals input to the optical sources, and for each of the associated portions, providing the instructions to the processor for setting the associated control levels for controlling at least some of the optical sources.

In another aspect, the optical signal router features a first level optical configuration processor, and a second level optical signal path configuration processor. The first level optical processor has a structural configuration, which, in response to optical signals from the optical control generator optical energy output port, enables the first level processor to receive and optically decode optical input packets of an optical data input signal. The second level optical processor, in response to optical signals

from said first level processor, provides an optical path from an optical data input to the processing system selected output.

In another aspect, the invention relates to an optical data signal processing method which features arranging a plurality of optical switches in a connection structure, each switch having at least one optical input port, at least a first and a second optical output port, and an optical control port for controlling the internal optical connection of a switch input port to one of the switch's output ports. The method further features optically connecting each of a plurality of electrically controlled optical energy sources to at least one of the optical control ports, connecting to each source an electrical signal input control signal and providing an optical energy output signal in response thereto, and flexibly generating and controlling electrical signals input to at least a plurality of said optical sources for managing the optical route of an optical data input signal through the processing system to a processing system selected output.

In accordance with the invention, the resulting method and apparatus advantageously create a high speed, flexible, routing system in which the optical input from a network is maintained in its optical signal state throughout the router without being changed to, for example, electrical data signals. The resulting cost savings in material, flexibility and increased throughput and bandwidth, with shorter latency in the switch, provide a superior improved performance which was previously unobtainable.

Brief Description of the Drawings

Figure 1 is a schematic representation of a typical network in which the invention can be advantageously employed;

Figure 2 is a schematic representation of a three switch tree structure using optical switches according to the invention;

Figure 3 is a more detailed schematic representation of an optical switch and optical control source;

Figure 4 is a schematic representation of a more complex tree structure according to the invention;

Figure 5 is a loop-up correspondence table according to the illustrated embodiment of Figure 4;

Figure 6 is a flow chart description of operation of the software in accordance with the invention; and

Figure 7 is a block diagram illustrating the two level optical control structure according to the invention.

Description of Particular Embodiments of the Invention

Referring to Figure 1, the invention is used in connection with a fiber optic communications network 10 in which a plurality of locations 15a, 15b, 15c, 15d, 16a, 16b interconnect through a network having optical fiber links 12 connecting router nodes, such as illustrated router nodes 14a, 14b, 14c, 14d. More or fewer locations, links and nodes can be used in other embodiments. Thus, for example, a message being sent from a source 15a can pass through nodes 14b and 14c before arriving at its destination, for example, destination location 16a. In the process of passing through nodes 14a and 14b, in accordance with the invention, there is provided at those nodes optical switching capability which does not require that the optical signal input coming

from the optical fiber link 12 be converted to an electrical signal within the router node 14 and then reconverted to an optical signal upon leaving the node for travel over the next fiber link. In this way, the latency within the node is substantially reduced, and the bandwidth of the nodes 14 is made comparable to the bandwidth of the optical fiber connecting to the input and output ports of the node. Also, the electronic component count can be substantially reduced.

In accordance with the invention, therefore, referring to figure 2, a typical router node 14 has a plurality of optical switches 20 through which the data will pass. Typically, the data is in the form of data packets having header information designating, among other things, the destination address to which the data is to be directed. The node is able to read the data packet header and based upon the header information sets the optical switches 20 to direct the incoming optical signal over a fiber link 22 to the correct outgoing optical signal link 24. In figure 2, there is illustrated the beginning of a particular structure which implements a tree type decision configuration for routing the signals from the input link 22 to the output link 24. Other decision tree configurations can be implemented and controlled for different decision based switching, and a larger tree structure, such as that illustrated in figure 4, can be employed. Yet other configurations can be employed to route the optical signals from the input port to a selected output port.

Each optical switch 20 has at least one input port 26, and at least two output ports 28. Typically, for simplicity, the optical switches, for example those manufactured by JDS Uniphase/Cronos, Research Triangle Park, N.C., have a single input port and two output ports with the optical switch acting like a single pole, double-throw switch to

direct the signal at its input port to one of its output ports. Each optical switch is controlled by an optical signal input at its optical control port 30. Typically, the optical level of the signal at the control port determines the state of the optical switch.

Referring to Figure 3, an optical control source 50, for example, an optical driver such as a laser diode, provides an optical signal over an optical path 52 to the control port 30 of optical switch 20 to control the switch state of the optical switch. The optical source can be typically controlled by an electrical signal 54 at its input electrical port 56. The derivation of that electrical signal is described in more detail below. As a result, the electrical signal input to the optical source 50 thus controls the state of the optical device 20 and designates thereby the output port 28 to which the signal at the input port 26 of the device is directed.

Referring now to Figure 4, there is illustrated an array of optical switches, comparable to an integrated circuit programmable array logic, for implementing a decision tree structure protocol specification in accordance with the invention. Consider, then, a specification protocol whereby the incoming destination address is used in a tree structure to determine the output port to which the input packet should be directed. In its simplest implementation, the protocol can define the destination address to correspond to the output port for the switch in a one to one correspondence. Thus, referring to Figure 4, each output port is labeled with its binary address starting at address “0000” through address “1111”. (In other embodiments of the invention more optical switches will typically be employed.) Accordingly, if the destination address were “0110”, the system must provide a path through the optical switches, 20a, 20b, ..., 20o from the input port 26 of optical device of 20a to the output port 28a of optical switch

20k. While there are many ways for implementing such a system, one convenient way is to create a correspondence table, such as that illustrated in Figure 5, so that when the destination address is decoded, the control inputs at ports 30 of each of the optical switches 20 will receive a signal as designated in the table of Figure 5. Therefore, for a switch having a binary output port designated by “0110”, the system would read the values stored at a line 54 of the table of figure 5 and apply the designated control values in the table to the optical switches 20. It is important to note that in this illustrated embodiment of the invention, only four optical switches need be deterministically set in accordance with specific destination values; each of the other optical switches has a “don’t care” control input, meaning that the connection from its input to its output ports does not take part in the routing process for that destination. This can be useful, for example, when there is more than one input line and multiple communications signals are being optically transmitted through the router switch. Accordingly, referring to Figures 4 and 5, if the destination address was “0110”, control signals would be sent to switch devices 20a, 20b, 20e, and 20k. The values of those optical signals would be “1”, “0”, “0”, and “1”, respectively, so that switch 20a, upon receiving a control signal of “1”, outputs its input signal at its upper output port 28a; switch 20b outputs its input at its lower output port 28b, corresponding to a “0” control input, switch 20e then directs the signal to its lower output port 28b; and optical device 20k directs the signal to its upper output port 28a (corresponding to a control input of “1” at device 20k). In this embodiment, the destination can be determined by the system by reading the header of the optical packet being transmitted.

As noted above, still referring to illustrated embodiment of Figure 4, none of the other optical devices 20 take part in the routing of the optical data signal through the switch. Accordingly, the state of those devices, and in particular, the signal at each input optical control port for those devices, does not take part in controlling the flow of the optical signal through the router. As a result, those optical switches can, in accordance with the invention, be used in other routing functions if the protocol specification and the system implementation permit it.

While not shown in Figure 4, each of the optical switches 20a, 20b,..., receives its control input directly, or indirectly, through the actions of an optical control source 50. The optical control sources 50, which may have a one-to-one correspondence to optical switches 20, or which may have a different correspondence to optical switches 20 as will be described in more detail hereinafter, are the elements which, generally, are directly controlled by reading the table of Figure 5. Thus, in accordance with different embodiments of the invention, the optical sources 50 can connect directly to the optical switches 20, or can connect through various optical circuitry, either preconfigured or itself configured in accordance with other control elements 50 attached thereto, in order to provide a complete operating circuit configuration which routes the input signal to the selected output port. This level of flexibility enables the configuration of switches according to the invention to have maximum flexibility in configuration and performance.

Referring now to Figure 6, there is described in broad terms the methodology of a particular embodiment of the invention. An exemplary apparatus for implementing that methodology is illustrated with reference to Figure 7. Initially, the system receives a specification protocol at step 70 and generates from that protocol control signals for

configuring a decision tree controller 72. A processor/configuration generator 74, operating in accordance with United States Patent Application Serial No.09/360,224, entitled “Method for Encoding and Decoding Data According to a Protocol Specification”, filed June 23, 1999, takes the human readable protocol specification 75 and generates the necessary electrical signals to control optical source drivers within the decision tree controller 72. Those electrical signals are passed to the decision tree controller 72 over lines 76. Once the decision tree controller has been properly configured in accordance with the protocol specification (this is the “first level configuration”), by the signals from the configuration generator 74, as indicated at step 78, optical data packets input over an optical fiber 80 can then be processed by the router. The incoming optical data packet over fiber 80 is fed to both a decision tree router optical switch circuit 82 and the decision tree controller 72. At the decision tree controller 72, the incoming packet is read (step 84) and, because of the manner in which the decision tree controller was configured by the generator 74, the destination for the packet and data stream lengths are determined, using optical processing, and the decision tree router 82 is configured, immediately (in optical processing time) so that the packet data is routed to the correct optical output line 88. The configuring of router 82 is the “second level configuration.” The generation of the control signals by the decision tree controller, an optical signal processor, indicated at step 90, occurs in the same manner that an electrical signal processor will read the beginning of an electrical data packet to determine the destination address, except that the processing is performed optically in accordance with the protocol specification. Once the packet has been read and routed to a next destination, the system reads a next packet at 94 and

generates the new (if necessary) destination control signals over lines 98 from the decision tree controller to the decision tree router. Preferably, the decision tree router has a structure comparable to that illustrated in Figure 4, which is a simple tree structure, wherein each of its optical switches is controlled one of the an optical signals over lines 98.

In accordance with the invention, therefore, the processor/configuration generator 74 receives a protocol specification and generates from the protocol specification the necessary optical signals over lines 76 to configure the decision tree controller 72. The decision tree controller, an optical data processor, can be periodically reconfigured in accordance with different or updated protocol specifications input to generator 74. The operations for performing these functions are illustrated in United States Patent Application, Serial No. 09/360,224, filed June 23, 1999 and titled "Method ofr Encoding and Decoding According to a Protocol Specification", the contents of which are incorporated herein by reference and attached hereto as Appendix A. In particular, the decision tree controller is comparable to a programmable array logic for implementation of the necessary decoding functions to read and optically decode the incoming optical data packets in accordance with the protocol to which they adhere. Clearly, therefore, different packet protocols can be implemented and the decision tree controller can be structured, and then configured, so that it can not only produce the signals on lines 98 for a specific routing, but further, it can also determine which packet protocol was used for encoding the packets being received on lines 80. The process for this determination in electrical systems is well-known and a comparable system methodology is used for the optical switches which are described above. Furthermore,

the invention described in the above-identified patent application enables the complex and seamless automatic generation of the necessary control signals over lines 76 to configure the decision tree controller optical switch "circuitry" 72.

It is important to recognize that the particular configurations of systems illustrated in the figures are not the only configurations in which the invention can be implemented. Thus, the processor/configuration generator 74 and decision tree controller 72 can be merged into a single element, the decision tree controller can be inflexible and designed for only one protocol, the decision tree router can be replaced by routers of other configurations, or can be a fixed configuration, etc. Thus, additions, subtractions, and other modifications and embodiments of the invention will be apparent to those practiced in this field and are within the scope of the following claims.